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Improved Efficiency and Power Density for Thermoacoustic Coolers

by

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Work continues on building a thermoacoustic heat driven cooler having no moving parts, with cooling power in the 0.5 to 1.0 kW range. Previous work dealt with numerical modeling of a new engine topology used in the above engine and various work on improved heat exchangers. Recently, more modeling suggests that cooling powers in the range of 35 kW (10 ton) may be possible with an engine having a longest dimension of 4 ft. and that efficiency improves significantly with size. Also, we have solved some fabrication problems with our high temperature nickel heat exchangers.

The major work this year has been on the high temperature thermoacoustic stack structure. A common Stirling engine regenerator structure consisting of stacked disks cut from stainless steel wire mesh was tested in an apparatus previously used for high amplitude heat exchanger measurements. Stacks are very easy to construct in this fashion and longitudinal thermal conduction is greatly reduced. Results show that amplitude performance is very good and within 10% of the usual spiral roll structures. More impressively, the efficiency of the mesh stack is as much as 30% higher than for spiral rolls stacks. We are also conducting measurements on pure carbon random structures that could be used at extremely high temperatures.

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Annual Summary Report for
Improved Efficiency and Power Density for Thermoacoustic Coolers

June 1996

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ABSTRACT

Work continues on building a thermoacoustic heat driven cooler having no moving parts, with cooling power in the 0.5 to 1.0 kW range. Previous work dealt with numerical modeling of a new engine topology used in the above engine and various work on improved heat exchangers. Recently, more modeling suggests that cooling powers in the range of 35 kW (10 ton) may be possible with an engine having a longest dimension of 4 ft. and that efficiency improves significantly with size. Also, we have solved some fabrication problems with our high temperature nickel heat exchangers.

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Improved Efficiency and Power Density for Thermoacoustic Coolers

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I Project Description

The goal of the proposed basic research is to consider and evaluate new thermoacoustic cooler designs which will lead to substantial improvements in both efficiency and cooling power density. The hope is that this technology will be viable for small temperature span and high cooling power needs such as equipment chilling and A/C. The specific design aspects to be considered are the acoustic resonator, the stack, and the internal heat exchangers. Substantial improvements in both the efficiency and the cooling power density of thermoacoustic refrigerators is necessary in order for the technology to be competitive with existing refrigeration technology.

II Approaches Taken

Reasonably high cooling power densities can be obtained if high acoustic amplitudes and high mean pressures can be used effectively. Acoustic amplitudes having a peak dynamic pressure that is at least 10% of the mean pressure are necessary ($p_o/p_m = 0.1$) and a value of 20% or higher is desirable. Our work focuses on improving the acoustic resonator, the heat exchangers, and stack to work efficiently at these amplitudes. It is also desirable the engine be as compact as possible.

Most of our effort is expended on experimental work, although numerical models are used to evaluate new designs and optimize chosen designs. Some of the experimental work is relatively basic or fundamental in scope, although we are working hard on building a fully working heat driven cooler in the 1 kW range that will integrate all of the basic improvements that we have developed over the previous two years. While the goal of these engines is to use heat sources such as fossil fuels or waste heat to produce refrigeration, our laboratory unit will initially use electric heat for reasons of convenience, simplicity, and to improve the quality of the measurements.

While we have previously focused on acoustic resonators and heat exchangers, this year considerable effort was given to the thermoacoustic stack. Our usual thermoacoustic refrigerator stack consists of a spiral roll of plastic film with thin spacers glued to the surface. These stacks are moderately difficult and time consuming to fabricate. Making comparable stacks for use at high temperatures is a considerably more difficult, since few materials (e.g. adhesives or solders) will tolerate the required temperatures.

Researchers at Los Alamos National Laboratory have successfully fabricated spiral roll stacks using metal foil, for use at high temperatures, but they have two draw-backs. First, fabrication requires a very tricky welding procedure; and second,

a substantial fraction of the engine's heat input is wasted by thermal conduction in metal foil.

We have chosen instead to pursue some basic experimentation on a stack structure that is in common usage in Stirling engine regenerators. This structure consists of stacking disks cut from stainless steel wire mesh into a holder tube. The measurements were done in two phases: Quick and dirty measurements were done in an open liquid nitrogen prime mover (a.k.a. the "Hofler tube") with a large number of different stacks including a spiral roll stack for comparison. Secondly, two good performing stacks from these measurements and another spiral roll stack were measured in a more sophisticated sealed prime mover apparatus. This apparatus had been previously used for heat exchanger measurements.

The results of these stack measurements have been very promising and we plan to use a wire mesh stack for the driver portion of the heat driven cooler engine, and will probably also try a wire mesh stack in the refrigerator portion.

III Summary of Completed Work

Numerical Analysis

A small amount of time was spent modeling a hypothetical heat driven cooler, that is increased in scale relative to the 0.5 kW unit that we are currently building. By selecting moderately aggressive pressure amplitudes and mean pressures and then scaling the dimensions up, we were able to generate results for a 35 kW (10 ton) cooler that is only 4.5 ft. in length. This design is the same as the "dual full wave" topology discussed previously. The calculated total COP is 0.65, and we believe that total COPs approaching unity (heat input equal to cooling power) are possible with a more serious optimization and possibly higher temperatures.

Heat Exchanger Fabrication

We have encountered some difficulty in fabricating some of our heat exchangers. The ambient and cold heat exchangers are easy to make, and have a moderately elaborate support and conduction backbone that is formed by a CNC milling procedure. The backbone pattern is cut into a heavy layer of electroplated copper.

The problem is with the high temperature exchanger which is made entirely of nickel. The electroplated nickel is very hard and tends to destroy cutting tools, and it is also prone to brittleness and breakage.

The simple and highly effective solution was to cut the pattern via a process know as "sink EDM" (electro-discharge machining). The disadvantages are cost and time wasted in procurement.

Engine Construction

Most of the parts are now available for the heat driven cooler. There have been some large procurement delays, particularly with some final heat exchanger pieces. There is a moderate amount of assembly to be done. We hope to have prime mover data and possibly refrigeration data by the end of the fiscal year.

The Mesh Stack

We have performed basic performance measurements on stacks made of stacked wire mesh disks. Initial measurements were made on dozens of different mesh sizes in an open prime mover, in an anechoic chamber. The measured quantities were external temperatures and far field sound pressure. The amplitudes achieved with the best mesh stacks were almost as high as with a spiral roll. The best mesh stacks were made with the most open mesh material we could obtain, which was "bolting cloth" with 10 wires per inch or "bolting-10". The bolting cloth material has extra-fine wires. Surprisingly, the hole size at 10/inch is roughly 3 times larger than the plate separation distance in the spiral roll stack.

Three stacks were then measured in a sealed temperature-controlled prime mover apparatus previously used in heat exchanger measurements. The apparatus allowed mean pressure and stack position to be varied and the heat input power to be measured. Also, internal pressure (dynamic and mean) were measured, as were internal temperatures.

The amplitude performance seen in the open prime mover was again confirmed, with the spiral roll being the best, followed by the "bolting-10" mesh, followed by "bolting-16." The amplitude difference was approximately 10% between the spiral roll and bolting-10. The highest amplitude for bolting-10 was $p_o/p_m = 29\%$.

The more interesting data was the "efficiency" data. Let me emphasize that the only acoustic load on the stack was the resonator itself. Furthermore, the acoustic power dissipated by this load was not measured but only inferred by assuming a quadratic dependence on amplitude. Comparing the results for the three different stacks suggest that the efficiency of bolting-10 and bolting-16 stacks were identical and were generally higher than for the spiral roll. In some cases the mesh stack efficiencies were 30% higher than for the spiral roll stack.

We are currently taking data in the same apparatus with stacks fabricated with a random carbon material. The amplitude data looks good and the "efficiency" data is currently being analyzed.

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